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A SUMMARY OF CURRENT INFORMATION ON NICKEL

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ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

NICKEL

Nickel Conservation Orders

'Ban on Nickel.' *Metal Industry*, 1951, vol. 78, June 22, p. 512.

As from June 22nd, 1951, a ban is placed on the use of nickel in a wide range of industrial, commercial and domestic equipment. The regulations imposed, which are necessitated by the requirements of the Defence Programme, are covered in two Orders:

Nickel Prohibited Uses (Ministry of Supply) Order 1951, No. 1048.

Nickel Prohibited Uses (Board of Trade) Order 1951, No. 1049.

The principal materials involved are nickel silver, cupro-nickel, Monel and the austenitic stainless steels. Provision is also made for extensive control of the application of nickel plating.

The Orders came into operation on June 22nd, 1951. Makers of prohibited articles are, however, allowed until October 1st to use up stocks of components made of the banned materials which they may already hold, and the provisions relating to nickel plating will not come into force until August 22nd.

The Orders are obtainable from H.M.S.O., price 4d. each.

Nickel Control Orders operative in the U.S.A. are referred to in a review of current regulations contained in *Steel*, 1951, vol. 128, June 25, pp. 76-81.

Production of Catalytic Masses by Atomization of Metals

W. J. C. DE KOK and H. I. WATERMAN: 'Preparation of Metals in a Finely Divided State for Use as Catalysts.' *Jnl. Applied Chemistry*, 1951, vol. 1, May, pp. 196-8.

The authors describe experiments (carried out before 1939) in which the materials, in the form of wire, were atomized under pressure by a process similar to the Schoop method. The gases used in the pistol were oxygen and acetylene for melting the wire, and compressed air for spraying.

In order to collect the particles in the finest possible state of sub-division, the stream of atomized particles is directed perpendicularly onto the surface of a non-inflammable liquid. Thus cooled, they sink in the liquid without agglomeration, and the spraying gas escapes along the surface.

It has also been found possible to atomize metals and alloys against a very smooth surface, e.g., a glass plate, to produce a thick porous metal sheet or screen which can easily be detached from the backing plate, and may be used as a catalyst mass. For certain purposes such forms of catalyst may have advantages over finely divided metal in powder form.

Some experimental details are given of atomized catalysts prepared from the following materials: nickel, 80-20 nickel-chromium alloy, Monel, and austenitic nickel-chromium steel. The spherical particles produced ranged from 0·002 to 0·08 mm. They were found to be superficially oxidized, and both the powders and the nickel screens produced by the method referred to above proved to be inactive when applied to the hydrogenation of hexadecene (cetene) and linseed oil (at 190° and 195°C., respectively), at a hydrogen pressure of about 200 atmospheres.

Reduction by heating for 2½ hours at 350°C. in a stream of hydrogen failed to produce activity, and chemical treatment, with caustic soda and concentrated ammonia was also ineffective. Activation treatment with sodium hypochlorite solution, a process previously used for treatment of nickel catalysts (LUSH: *Brit. Pat.* 221,000), proved, however, to give entirely satisfactory results; particulars are given of the conditions of activation used for each of the materials examined. All four powders, after activation, catalyzed the hydrogenation of hexadecene and linseed oil, but in the case of benzene only nickel and nickel-chromium alloy were effective.

ELECTRODEPOSITION AND OTHER COATING METHODS

Conservation of Nickel: Production of Nickel Salts from Nickel Anodes

N. HALL and G. B. HOGABOOM: 'Nickel Salts from Nickel Anodes; Porous Pot Method.' *Metal Finishing*, 1951, vol. 47, May, pp. 66-7, 70.

The Amendment of N.P.A. Order M.14, permitting the use of nickel anodes on hand with platers at March 1st, 1951, for nickel plating beyond the date fixed in the original Order, has placed many U.S. platers in the position of having sufficient anodes to ensure operation for some time, but of being unable to purchase nickel sulphate and nickel chloride in quantities sufficient to fulfil their orders. This position has led to consideration of the porous-pot method for maintenance of industrial plating solutions: the present article emphasizes the practical possibilities inherent in the procedure. An account is given of results obtained by its use on an industrial scale, in maintaining a 2700-gallon semi-automatic bright-nickel-plating tank. The article includes a diagram showing a schematic layout of a porous pot for generating nickel sulphate or nickel chloride, and gives full details of the method, the chemistry involved in the process, operating costs, and results obtainable.

While it is conceded that under normal conditions replenishment of electrolytes by this method would not be considered, it is urged that during the present emergency such procedure should be welcomed as a means of maintaining solutions at optimum concentrations, by those who have sufficient anode material in stock.

Electrodeposition of Nickel on Zinc- and on Aluminium-base Materials

AMER. SOC. TESTING MATERIALS: 'Report of Committee B-8 on Electrodeposited Metallic Coatings.'
A.S.T.M. Preprint 13, June, 1951; 27 pp.

Report of the Committee's activities 1950-1951, recommendations for modifications in standards relating to electrodeposited metallic coatings, and proposals for new Tentative Recommended Practices. Details of the new schedules are given below:—

'*Preparation of Zinc-base Die Castings for Plating*'

This covers the following steps involved in preparation of zinc-base materials for plating with nickel and chromium or other coatings:—polishing of parting lines, polishing of other surfaces as required, buffing, pre-cleaning and rinsing, alkaline cleaning (electrocleaning) and rinsing, acid dipping and rinsing, and copper striking. Following the copper strike the work may be coated with any other metal by normal plating cycles.

'*Preparation of and Plating on Aluminium Alloys*'

The zinc-immersion method is considered to be the most generally suitable pre-plating procedure: the schedule therefore provides for this form of preparation. The nature of aluminium is briefly discussed, (1) from the point of view of the microstructure of the various types of alloy as affecting their suitability for plating, and (2) with regard to the naturally forming oxide film which requires removal, if adherent deposits are to be obtained.

Cleaning and conditioning treatments requisite before zinc-immersion are described: these vary according to the nature of the alloy being treated. For the actual zinc-immersion treatment the following solution is recommended: sodium hydroxide, commercial grade (76% Na_2O) 70 oz./gall.; zinc oxide, technical grade, 13 oz./gall. Procedure is described, with notes on precautions to be observed, and characteristics by which satisfactory zinc coatings can be recognized.

After such treatment the surface may be plated with other metals, by any of the methods suitable for electrodeposition on zinc-base materials, but it is considered advisable to apply a preliminary copper strike prior to deposition of silver, brass, nickel, or chromium. Particulars are given of solutions and operating conditions suitable for plating of the processed surfaces with brass, cadmium, copper, chromium, gold, nickel, silver or zinc.

Recommendations are also made on racking procedure, and attention is directed to the primary importance of using effective rinses at all stages in the plating procedure.

For nickel-plating on the zinc-processed coppered surface the following types of bath are suitable:—

Watts-Type Solutions (Dull Nickel)		
	oz./gall.	g./L.
Nickel sulphate crystals	30	225
Nickel chloride ..	6	48
Boric acid	5	37·5
pH	5	
Temperature	130°-140° F. (54°-60° C.)	
Current density ..	40 amp./sq. ft. (4·3 amp./sq. dm.)	

Bright-nickel-plating solutions are also satisfactory for use on aluminium alloys. The usual types may be used, with due regard to limiting conditions recommended by the vendors.

In nickel-plating of aluminium alloys the normal precautions should be observed, i.e., frequent carbon treatment, continuous purification, and filtration. For applications in which corrosion is not a critical factor, coatings of the order of 0·3-0·5 mil (8-13 μ) are satisfactory. For service in corrosive conditions 1-2 mil (25-50 μ) is recommended, and the application of a final chromium coating (0·01-0·02 mil) is advisable.

An appendix to this schedule concisely summarizes the cleaning, zinc-immersion, cleaning and conditioning treatments.

'*Preparation of, and Plating on, Stainless Steel*'

The information given is presented as an aid to electroplaters who, although familiar with electrodeposition procedure for plating the more common metals, may encounter special problems in plating on stainless steel. The nature of stainless steels, and the consequent difficulties presented in plating are briefly reviewed, and full details are given for cleaning, activation and plating.

The preparation of these steels for plating involves three major steps:—

(1) removal of scale (by blasting, shot-peening or wheel abrading, sand-blasting or tumbling, pickling, treatment in a molten salt bath, or wire brushing). An appendix to the schedule gives details of procedure to be used in all these methods.

(2) removal of oil, grease or other foreign materials by cleaning. This is usually effected by spray-cleaning, using an alkali or emulsion-type cleaner. Soak cleaning or vapour degreasing may also be employed. Recommendations are made on technique of cleaning,

(3) activation, immediately before plating. Particulars are given of solutions and procedure which may be used for cathodic, immersion, and simultaneous activation-plating treatments. It is noted that in some cases more than one type of treatment may be required to ensure a high degree of adhesion: an example of procedure successfully used in the automotive industry is given.

Recommendations are made on rinsing which should follow the activation stage and some notes are added on the conditions to be observed in electrodepositing nickel or chromium on the prepared surfaces.

Particulars are also given with regard to stripping methods, post-plating operations (stress-relieving, buffing or colouring, forming, etc.), and methods of testing for thickness, hardness and adhesion.

See also—

Exposure Tests on Nickel-Plated Steel Panels

'Report of Sub-Committee II on Performance Tests; Atmospheric Exposure of Copper-Nickel-Chromium Deposits on High-Carbon Steel.'
A.S.T.M. Preprint 13S, June, 1951; 10 pp.

This report, issued as an appendix to the report of the main Committee, is essentially a continuation of one issued in 1949, in which details were given of preparation of test panels and exposure tests at

various locations; see *Proc. Amer. Soc. Testing Materials*, 1949, vol. 49, pp. 220-38; *Nickel Bulletin*, 1949, vol. 22, Nos. 8-9, p. 137.

This later report covers results not available in 1949, reviews all the data obtained from inspection of the specimens throughout the exposure period, and summarizes the conclusions resulting from the tests.

The exposure periods were 3-3½ years approximately, and were made at locations representing marine, normal urban, contaminated urban and country atmospheres. Comparison is made of nickel coatings deposited (1) directly on steel, (2) over a copper flash, (3) over heavy copper deposits, (4) over buffed copper, (5) over nickel. Behaviour of bright nickel is compared with that of dull coatings, and consideration is given to the influence of pH of the bath from which the deposits were made, and of the degree of polish of the steel plated.

The Committee considers that within the range of variables represented by the test panels, and the limitations inherent in atmospheric-exposure tests, the following conclusions are justified:—

'(1) The type of atmosphere to which copper-nickel-chromium deposits on steel were exposed had a very large effect on the rate of their deterioration as protective and decorative coatings.

'(2) The thickness of the nickel plate, either directly plated on steel or as an intermediate component of a composite copper-nickel-chromium coating, was the principal determining factor in the atmospheric weathering characteristics of such coatings on steel, in the wide range of atmospheres represented in the tests.

'(3) The copper undercoatings (a cyanide copper strike or a cyanide copper strike plus acid copper) added little to the protective value of composite copper-nickel-chromium coating on steel, and what little they did add was important only in the early stages of deterioration or in the mildest corrosive atmospheres.

'(4) Buffing of a copper undercoat in a composite copper-nickel-chromium deposit on steel may have had a slightly beneficial effect in the early life of such coatings or in mildly corrosive atmospheres, but the effect was minor and was not persistent.

'(5) Applying a nickel coating in two steps, with the first layer buffed, or annealed and buffed, was highly beneficial in a sea-coast environment, but was of no benefit in industrial atmospheres.

'(6) The type of nickel plate (dull, semi-bright, or bright) exerted no important influence on coating life, at least within the range of plate types included in the tests.

'(7) Identical coating systems, within the range of the simple and composite coatings studied, behaved similarly on a high-carbon steel base and on the low-alloy, high-yield-strength steel tested.'

Ratings given on similar panels by means of the salt-spray test (200 and 500 hours' duration) were correlated with the results of the atmospheric-exposure tests. Little or no relationship between the two series of results could be established, although the salt-spray results confirm that the coatings on the panels were satisfactorily representative of good plating practice. It is emphasized, however, that this lack of correlation with atmospheric results is in no sense a condemnation of the salt-spray as a routine quality-control procedure. It merely demonstrates the impossibility of using the accelerated test as a means of distinguishing between different types of coating with respect to behaviour under atmospheric exposure.

Nickel Conservation Orders

See abstract on p. 148.

Electrodeposition of Nickel from Fused Ammonium Salts

F. H. HURLEY and T. P. WIER: 'Electrodeposition of Metals from Fused Quaternary Ammonium Salts.' *Jnl. Electrochemical Soc.*, 1951, vol. 98, May, pp. 203-6.

Electrolytic studies on fused mixtures of ethyl pyridinium bromide and metallic chlorides showed that the following metals can be deposited on the cathode: silver, copper, bismuth, lead, tin, nickel, cobalt, cadmium, iron, zinc, and aluminium. Tests involving metallic sulphates and nitrates, as well as mixtures employing fused benzyl pyridinium bromide, indicated that these metals can be deposited except in cases where non-ionic complex compounds are formed. Mixtures containing nickel chloride failed to give adequate current conduction.

A more detailed investigation was made of electrodeposition of aluminium from *N*-substituted pyridinium salts.

Corrosion-Resistance of Tin-Nickel Alloy Coatings

S. C. BRITTON and R. M. ANGLES: 'Corrosion Resistance of Electrodeposited Tin-Nickel Alloy.' *Electroplating*, 1951, vol. 4, June, pp. 201-3. Based on paper read before the Electrodepositors' Technical Society, May 21, 1951.

The authors reported corrosion tests made on the type of tin-nickel alloy coating described in the paper by Parkinson presented at the Annual Conference of the Society, Apr., 1951: see *Nickel Bulletin*, 1951, vol. 24, No. 5, p. 101.

The corrosion tests reported were made in two groups:—

(1) *Exposure of thick* (0·003-*in.*) *deposits of tin-nickel alloy on brass, to a wide range of corrodents*, to assess the probable fields of usefulness of the coating, and to obtain additional information on the fundamental characteristics of its corrosion-resistance. These tests consisted of part-immersion in acid, salt, and caustic-soda solutions, at 30°C., and exposure to corrosive vapours; dry-oxidation tests; handling test; contact with foodstuffs and beverages; 96-hour part-immersion tests in solutions which in the 30-hour tests had appeared to be slightly corrosive; full immersion at 80°C. in solutions selected from the part-immersion tests as likely to cause corrosion; electrode-potential measurements; and corrosion in couples with steel, brass or copper.

(2) *Exposure, to actual or simulated atmospheric conditions, of thinner deposits, on steel or brass.* The

thicknesses were within the normal commercial range for decorative coatings, in order to assess the effects of porosity and thickness of coating required to give protection. The exposures were made out of doors (at Perivale and in a coastal atmosphere), contaminated atmospheres were simulated by exposure over sulphur dioxide and over hydrogen-sulphide solutions, and samples were exposed in a domestic kitchen.

From the results of all the tests it is concluded that the tin-nickel deposits will satisfactorily withstand exposure to a variety of environments which are corrosive to some other metals. It is evident, however, that porous tin-nickel deposits on steel may be disfigured by corrosion of the basis material. It is considered that to ensure good service in conditions of moderate severity a minimum thickness of 0·0005 in. is desirable on brass and that for coatings on steel an undercoating of copper (0·0005 in.) is necessary, followed by 0·0005 in. of tin-nickel alloy. As in the case of other metals, optimum results will be obtained only in deposits made under well controlled plating conditions.

The tarnish-resisting qualities of the tin-nickel coatings place them in the same class as chromium. Comparison is being made of the behaviour of a range of thicknesses of tin-nickel alloy coating over nickel, with nickel+chromium-coated specimens.

Nickel-plated Materials for Analytical Weights

See abstract on p. 162.

NON-FERROUS ALLOYS

Thermal Conductivity of Nickel Alloys and Stainless Steel at Low Temperatures

R. BERMAN: 'The Thermal Conductivity of Some Alloys at Low Temperatures.' *Philosophical Magazine*, 1951, vol. 42, 7th ser., June, pp. 642-9.

Thermal conductivities of *nickel silver* (copper 47, nickel 9, zinc 41, lead 2, per cent.), *stainless steel* (titanium-stabilized 18-8 chromium-nickel containing 0·1 per cent. carbon) and *Constantan* (copper 60, nickel 40, per cent.) were determined over the range 2° to 90°K. (−271° to −183°C.), and the electrical conductivity was measured at a few temperatures in this interval.

The electronic contribution to the heat conductivity was estimated, and by subtracting this from the total conductivity the lattice heat conductivity is deduced. This forms an appreciable fraction of total conductivity over the temperature range involved. Up to about 25°K. (−248°C.) the lattice conductivity is limited mainly by scattering of the lattice waves by electrons, but above this temperature 'impurity' scattering predominates.

Nickel Conservation Orders

See abstract on p. 148.

Analysis of Monel

W. L. MILLER and G. NORWITZ: 'Determine Silicon-Copper-Iron in Monel Metal.' *Amer. Foundryman*, 1951, vol. 19, May, p. 80.

The authors describe a method based on that proposed by CLARDY, MAUPIN and GIBBS (*Ind. Engg. Chem., Anal. Edn.*, 1941, vol. 13, p. 88), but modified to reduce the time required.

A 1-gram sample is dissolved in nitric acid and perchloric acid, and is evaporated to fumes of perchloric acid, as described by Clardy et al. (*loc. cit.*). The copper is electrolyzed directly on the silicon filtrate, after addition of nitric acid. Iron is determined colorimetrically on the copper electrolyte, by a rapid method, using thiocyanate. Full details of procedure are given.

The authors have found that by using a 1-gram sample no significant amounts of chlorine are formed on fuming with perchloric acid. It is, therefore, unnecessary to boil the silicon filtrate before electrolyzing for copper. In the thiocyanate colorimetric procedure for determination of iron, hydrogen peroxide is used to stabilize the colour, as described by PETERS et al. (*Ind. Engg. Chem., Anal. Edn.*, 1939, vol. 11, p. 502). The present authors believe that they are the first to propose a perchloric-nitric acid medium for the colorimetric determination of iron by the thiocyanate method. If required, other elements can be estimated on the residual solution, after determination of iron.

Nickel-Aluminium-Silicon Alloys

J. N. PRATT and G. V. RAYNOR: 'The Intermetallic Compounds in the Alloys of Aluminium and Silicon with Chromium, Manganese, Iron, Cobalt, and Nickel.' *Jnl. Inst. Metals*, 1951, vol. 79, pp. 211-32; *Advance Copy* 1306; *Monthly Jnl.*, June, 1951.

The paper reports a study of the intermetallic compounds which occur in the ternary aluminium-rich alloys of aluminium and silicon with transitional metals of the first long period.

Since all previous workers have agreed that no ternary compounds occur in the aluminium-rich alloys of the aluminium-nickel-silicon system, the authors' experiments were confined to examination of the solubility of silicon in $NiAl_3$: the results indicate that it is little more than 0·6 at. per cent. The reason for this restricted solubility is not yet understood.

NICKEL-IRON ALLOYS

Nickel-Iron Alloy Magnetic Cores

W. S. MELVILLE: 'The Use of Saturable Reactors as Discharge Devices for Pulse Generators.' *Proc. Instn. Electrical Engineers*, 1951, Part III, vol. 98, May, pp. 185-204; disc., pp. 204-7.

The subject of recurrent high-power pulse generation may be considered as including pulse generators for radar modulation, nuclear-particle acceleration, impulse testing, and auxiliary and ancillary circuits such

as initiators and sub-modulators for more powerful discharge devices, e.g., ignitron igniter firing-circuits. In generators of these types it has been customary to use electronic discharge devices which depend for their operation on the conducting properties of electric arcs, as the means of rapidly discharging capacitive pulse-forming networks into appropriate utilization circuits. While these devices are, in general, satisfactory for many applications, it is well known that they have inherent disadvantages.

Comparatively recent developments in the field of high-permeability high-saturation-flux-density magnetic materials having characteristically rectangular hysteresis loops, together with new circuits designed to take advantage of their special properties, have made it possible to overcome many of the disadvantages of electronic discharge devices, by replacing them with static components having indefinitely long lives. The particular advantages obtained by the use of nickel-iron alloys of grain- and domain-oriented types, such as H.C.R. metal, or of materials such as Mumetal, which have a low anisotropy constant, are discussed. H.C.R. metal is well suited to applications in which the repetition frequency and the rates of flux change are sufficiently low for full advantage to be taken of the total available flux-density change of about 30,000 gauss; adequate properties have been preserved in this material when rolled to about 0·002-in. thick. Mumetal can be rolled to somewhat less than 0·001-in. thick without serious deterioration of its properties, and is therefore suited to applications involving high rates of flux change, such as the later stages of short-pulse cascade circuits. The available flux-density change is about one-third of that of H.C.R. metal. Tests show that Rhometal is also a suitable material in thicknesses greater than 0·002 in.; its available flux change lies between those of the other two materials and, because of its high resistivity, cores of this material are suitable for intermediate cascade stages. Precautions necessary to prevent impairment of magnetic properties by imposition of mechanical strain during core construction are considered. Tests on H.C.R. metal have indicated that its known property of having two preferred directions of magnetization at right angles may make possible, for pulsator cores, the use of the wide-yoke stampings of this alloy which have been developed for magnetic-amplifier components. The advantages of this type of core assembly are indicated.

The paper outlines the historical background to the development of some of the circuits and materials, and describes the operation of circuits designed to fulfil the duties of radar pulse-modulators and ignitron firing circuits.

CAST IRON

Heat-Treatment of Grey Cast Iron: I.B.F. Report

INST. BRIT. FOUNDRYMEN: 'Heat-Treatment of Grey Cast Iron. Report and Recommendations of Sub-Committee T.S.31.' *Paper* 1012, June, 1951; 8 pp.

The report is essentially a review of literature, supplemented by the experience of members of the Sub-Committee; it contains no results of new research work. It was presented at the 1951 meetings of the Institute, to provide opportunity for discussion on lines of future research.

The report is presented in sections relating, respectively, to the following heat-treatment operations:—

A. Annealing operations: (1) annealing for improved or maximum machinability, and (2) annealing for the removal of chill.
B. Heat-treatment to improve the hardness, wear-resistance and strength of cast iron, whether previously annealed or not.
C. Stress-relief treatment.
D. Heat-treatment prior to enamelling.
E. Surface-, or local-hardening, by flame and induction heating or nitriding.
F. Isothermal quenching.
G. (1) Heat-treatment of suitably alloyed iron, to develop a martensitic structure.
   (2) Heat-treatment of suitably alloyed iron, to modify an acicular structure.
H. Treatment of special irons at sub-normal temperature.

Processes under headings E-H inclusive are highly specialized and, where used commercially, are limited to applications which can hardly be considered as of wide general interest. They are therefore only briefly surveyed in the report. The final section includes reference to certain general points of heat-treatment technique: rate of heating; oxidation and growth during heat-treatment, and means for prevention, and steps which may be taken to avoid distortion.

In the light of the summary of information made by the Committee, its members make the following observations with regard to lines of future investigation:—

'Whilst there is a large volume of information on the question of pearlite breakdown in normal irons, there is little available information on the response of unusual compositions, and especially modern alloyed irons containing nickel, chromium, copper, molybdenum, either singly or in combination. The effect of graphite size and distribution as cast, also of section thickness, could also usefully be studied.

'Further investigation is desirable for the removal of massive free carbides in iron accidentally chilled, where the composition is unusual by reason of very low or very high silicon, unbalanced sulphur, or the presence of nickel, chromium, copper, molybdenum, either singly or in combination.

'The influence of the rate of cooling through the critical point, on the residual combined carbon of irons heat-treated at temperatures above the critical, is not at all clear, and could usefully be investigated in relation to the chemical composition.

'In any work which may be undertaken, or report issued, the critical point for the iron in question should be taken into consideration and methods for obtaining the critical point should be stated.'

Nickel-Molybdenum Acicular Cast Iron

MOND NICKEL CO., LTD.: 'Nickel-Molybdenum Acicular Cast Iron.'* *Publn.* 435, 1951; 15 pp.

In the early years of production of cast irons alloyed with nickel+molybdenum it was noted that some

* *We shall be pleased to supply a free copy of this publication.*

batches exhibited unusual strength and toughness, combined with high hardness, but that they also showed satisfactory machining qualities. The basic reason for this combination of characteristics was discovered through the work of Flinn and Reese, in 1941, when it was established that irons showing these qualities exhibited a special type of structure, now known as 'acicular'.

Since that time acicular cast irons have been increasingly used, and in 1948 Grade 26 of British Standard 1452 was introduced, primarily to cover irons of this type. The production of the irons is covered by British Patent 545,102.

This brochure describes changes of state which accompany the cooling of unalloyed cast iron, as a background to discussion of modifications introduced by alloying with nickel+molybdenum and by heat-treatment, and the conditions by which the acicular structure is produced. Typical photomicrographs illustrate the discussion. A table shows the amounts of alloy additions which should be made to produce the acicular structure in castings varying from ½-in. to 10-in. ruling section. Recommendations are also made with regard to the composition of the basis iron from which the acicular type is produced, and on melting and casting procedure, and heat-treatment.

Mechanical properties typical of the acicular cast irons, in the as-cast and the heat-treated conditions, are tabulated, in comparison with those of other grades of cast iron covered by British Standard 1452.

Applications of the acicular irons, which are reviewed and illustrated, include crankshafts, steam-hammer parts, camshafts, picking parts of textile looms, shell-nosing dies, and valve-rocker arms. In all of these applications a combination of strength, toughness and wear-resistance makes the acicular cast irons an important engineering material.

Development of Spheroidal-Graphite Cast Iron in France

M. BALLAY, R. CHAVY and J. GRILLIAT: 'Study of Some Properties of Spheroidal-Graphite Cast Iron.' *Assocn. Technique de Fonderie*, Preprint 10, June, 1951.

The paper is specifically designed to provide data in a form readily interpreted in the French foundry industry. It comprises a report of investigations on typical material produced by the new process, in French foundries working under the licence from The Mond Nickel Company, Ltd.

A highly detailed account is given of tests made on irons from nine casts; it includes notes on the testing technique employed to assess the tensile, impact, bend and other qualities of the irons, in both the as-cast and the heat-treated conditions.

The next part of the paper deals with the various forms of heat-treatment applicable to the new irons, and demonstrates the range of properties which can be produced by suitable selection of the conditions of treatment.

Consideration is then given to a number of miscellaneous physical properties characteristic of the magnesium-treated irons:—electrical resistivity, tensile modulus of elasticity and damping capacity, ductility at elevated temperatures, hot-hardness. Impact strength and notch-sensitivity are shown, on a comparable basis, for a good-quality grey cast iron of current production, three spheroidal-graphite cast irons (in various conditions), two cast steels in the as-cast condition, and a heat-treated rolled carbon steel. The modulus of rupture in bend of spheroidal-graphite iron (as-cast and heat-treated) was also determined, using various forms of test piece, and a study was made of the distribution of elongation occurring in tensile testing of these irons. The investigations also included tests of notched and unnotched bars, and a comparison of the mechanical properties of typical American malleable cast iron and spheroidal-graphite cast irons.

The final section of the paper contains a critical discussion of specification requirements which should be laid down for the ductile irons, and methods of test most suitable for assessment of their qualities.

The paper embodies a considerable amount of reference data, and is supported by a *bibliography* of some of the major literature.

Ductile Cast Iron for Gears

J. D. SHELEY: 'Ductile Iron Replaces Alloy Gear Castings, Forgings.' *Iron Age*, 1951, vol. 167, May 10, pp. 99-100. Reprint issued by International Nickel Co., Inc., 1951.

The article reports experience of the Black-Clawson Company, Hamilton, Ohio, in substitution of ductile (magnesium-treated spheroidal-graphite) cast iron for alloy steel and Ni-Hard castings and for alloy steel forgings.

A table shows properties being regularly obtained in large-scale production of as-cast and of heat-treated ductile iron. In the heat-treated condition tensile strength up to 216,000 p.s.i. (96·4 tons per sq. in.) and hardness of over 400 Brinell is reported.

Examples of applications in which the new iron has proved satisfactory are illustrated, e.g., a large spiral bevel gear, formerly made from a 4140 steel forging. The cast-iron blanks for the gears are annealed for 1½ hours at 1650°-1675°F. (900°-910°C.), slowly cooled to 1275°-1290°F. (690°-700°C.) and held at that temperature for 4½ hours, after which the gear is machined and the teeth are flame hardened. Spiral bevel gears in regular production range from 200 to 400 lb. in weight, and gears in the general range from 15 to 1500 lb. The wear-resisting qualities of the iron in this application have been found especially satisfactory.

A figure in the article shows a photomicrograph of a ductile iron weld, illustrating the absence of martensite in the heat-affected area.

Magnetic Properties of Spheroidal-Graphite Cast Iron

H. E. STAUSS: 'Magnetic Properties of Nodular Cast Iron.' *Foundry Trade Jnl.*, 1951, vol. 90, May 24, pp. 553-4.

The author, who is at the head of the Electric and Magnetic Alloys Branch of the Metallurgical Division, U.S. Naval Research Laboratory, has made an

interesting analysis of the data on magnetic properties of spheroidal-graphite cast iron presented by EVEREST to the Institute of British Foundrymen in 1950 (*ibid.*, 1950, vol. 89, pp. 57-64). Particular attention is given to the relatively high hysteresis loss found with the ductile cast iron.

The writer points out that the data reported by Everest may be interpreted to show that important differences arise in the magnetic properties of cast iron, depending on the form in which the graphite is present: the flake form of graphite has a greater and more deleterious effect than the spheroidal form. Stauss concludes that the lower value of hysteresis loss in flake-graphite iron, relative to nodular- or spheroidal-graphite iron, is probably the result of reduction of the magnetic induction of the flake-graphite iron resulting from flake-created gaps. The higher loss found in the new irons is therefore not a sign of poorer magnetic properties, but of better magnetic induction for like applied fields, H. On the other hand, the lower values of hysteresis loss observed in ferritic spheroidal-graphite iron, relative to the iron in the as-cast condition, is the result of true improvement of magnetic properties resulting from conversion of the matrix to ferrite.

A further contribution to the discussion (*ibid.*, 1951, vol. 91, July 19, pp. 69-70) is made by K. G. HINTON, a member of the staff of the laboratory in which the magnetic determinations reported by Everest were carried out. It is pointed out that the data presented in the original paper did not provide a complete basis for comparison of the properties of the flake-graphite and the nodular irons. Additional information is now given, and attention is drawn to the fact that the samples tested had the same chemical composition, apart from the nickel and magnesium contents, rather than the same matrix structure. The composition of the flake-graphite iron, which had been innoculated with ferro-silicon, was carbon 3·3, silicon 2·4, manganese 0·49, nickel 0·08, per cent., which gave a structure in which there was approximately 40 per cent. pearlite and 60 per cent. free ferrite (combined carbon 0·35 per cent.), whereas the as-cast spheroidal-graphite cast iron, which contained 0·71 per cent. nickel and 0·078 per cent. magnesium, had a pearlitic structure with about 20 per cent. free ferrite (combined carbon 0·7 per cent.). It is considered that if the amount of combined carbon had been the same in both cases, the hysteresis losses would not have been very different from one another, but the spheroidal-graphite iron would have shown its superiority by virtue of higher permeability at medium and high field strengths.

CONSTRUCTIONAL STEELS

Austenite Transformation in Nickel-Alloy Steels

E. A. LORIA: 'Kinetics of the Austenite Transformation in Certain Alloy Steels.' *Trans. Amer. Soc. Metals*, 1951, vol. 43, pp. 718-33.

The paper is the third in a series dealing with decomposition of austenite at sub-critical temperatures, in complex alloy steels. The first paper described the nature and mode of formation of the acicular structure found within the intermediate transformation range in two alloy steels containing appreciable amounts of carbide-forming elements (*ibid.*, 1948, vol. 40, pp. 758-74) The second paper summarized the results of isothermal transformation studies on a chromium-manganese-molybdenum hypoeutectoid steel and a nickel-chromium-molybdenum hypereutectoid steel (*ibid.*, 1949, vol. 41, pp. 1248-60).

This third report covers investigation of the isothermal transformation characteristics and structural features of complex alloy steels of the types below:—

C %	Ni %	Cr %	Mo %	Mn %	Si %	V %	P %	S %
0·60	2·75	1·25	0·50	0·60	0·30	0·12	0·035	0·024
0·59	—	1·06	0·54	0·96	0·28	0·12	0·032	0·022
0·86	2·47	1·21	0·50	0·66	0·38	—	0·040	0·024
0·42	2·71	1·00	0·48	0·67	0·31	—	0·030	0·022
0·39	—	1·00	0·56	1·10	0·29	0·12	0·015	0·013
0·31	—	0·99	0·52	0·76	0·27	0·11	0·016	0·013

Variations in the carbon and alloy contents of the steels permit comparison of transformation velocities, and provide information on hardenability and on structures resulting from slack quenching.

T.T.T. diagrams are presented, supplemented by photomicrographs and hardness data. The diagrams show a complete break, or region of relatively stable austenite, between the pearlite and bainite transformations. The top of the bainite range is marked by a horizontal 'shelf' extending to short reaction times, and the effects of carbon and alloy contents, on the time required for initial decomposition at any given temperature, are clearly indicated.

Influence of Nickel on Stress-Strain Characteristics of Steel

R. RARING, J. A. RINEBOLT and W. J. HARRIS: 'Effect of Alloying Elements on True-Stress/True-Strain Flow Curves of Pearlitic Steel.' *Trans. Amer. Inst. Mining and Metallurgical Engineers*, 1951, vol. 191, pp. 395-400; *Jnl. of Metals*, May, 1951.

Until recently nearly all studies of the effects of alloying elements on the tensile properties of metals have compared the conventional engineering parameters tensile strength, yield strength, elongation, and reduction of area. Lacy and Gensamer, Hollomon and others have, however, adopted the true stress-true strain method of reporting results from tension tests. For details of the definitions of stress and strain, and the analytical geometry of the stress-strain curve, reference is directed to GENSAMER'S discussion (*Trans. Amer. Soc. Metals*, 1946, vol. 36, pp. 30-60); supple-

mentary details are given of the method used by the present authors to determine energy-to-fracture.

The influence of carbon in plain carbon steels was studied in the range 0·01 to 0·63 per cent., and the basis steel used in the alloy-steel series was of the following type: carbon 0·30, manganese 1·0, silicon 0·30, per cent. On this steel determinations were made of the effects of the following elements, varied singly, within the percentage ranges shown in brackets: manganese (0·41-1·55); silicon (0·26-3·05); phosphorus (0·005-0·21); copper (0·03-2·00); chromium (0·05-1·10); nickel (0·04-3·15); molybdenum (0·11-0·29); vanadium (0·006-0·21). Some data are also reported on steels containing varying amounts of aluminium (to 0·09), boron (to 0·004), sulphur (0·007-0·137), and titanium (to 0·39). The influence of the respective elements was compared on the basis of fracture stress, fracture strain, energy-to-fracture, rate of strain hardening, strain-hardening exponent, height of the flow curve, and lower yield point.

All the elements studied, with the exception of aluminium, boron, sulphur, molybdenum and titanium, were found to increase the height of the flow curve; effects of the excepted elements were too small to permit reliable evaluation. Strain hardening increased as height of flow curve increased; the degree of the change varied with composition of the steels. Energy-to-fracture was increased by manganese, nickel and chromium, and was decreased by carbon, silicon, phosphorus, molybdenum, copper and vanadium.

Notch-Toughness of Hardened and Tempered Nickel-Alloy Steels

R. L. RICKETT and J. M. HODGE: 'Notch-Toughness of Fully Hardened and Tempered Low-Alloy Steels.' *Amer. Soc. Testing Materials, Preprint* 31, June, 1951; 14 pp.

Report of investigation made to determine the effect of composition hardness, and other variables, on the notch-toughness of low-alloy steels completely hardened (quenched to a fully martensitic structure), and tempered. The Charpy impact test, with keyhole-notch specimens, was used as a measure of toughness, and, in order to cover a wide range of composition and hardness, 25 low-alloy steels of representative types were studied. Most of these were commercial grades; some were special heats. They ranged in carbon content from 0·09 to 0·64 per cent., and each contained one or more of the common alloying elements, in amount sufficient to ensure that standard impact specimens could be completely hardened throughout by quenching in oil or brine. The fully hardened specimens were tempered for one hour at temperatures in the range 300° to 1150°F. (149° to 620°C.), and cooled in air.

The steels tested were of the following S.A.E. grades:

3312 (and 5 per cent. chromium-molybdenum)
2320, 3120, 4620, 4320, 8620 (and 3 per cent. chromium)
1330, 8630, 9430, 2330, 4130 (and 2 per cent. chromium and chromium-molybdenum)
1340, 8440, 8640, 9440, 3140, 2340, 4140 (and 0·5 per cent. molybdenum)
6150, 4063.

Special heats are shown in brackets, in association with the corresponding carbon-level groups of S.A.E. steels.

Test data obtained from examination of these steels, supplemented by comparable information from other investigations made by the authors, and by published data from other sources, led to the following conclusions:—

'(1) On the average, notch-toughness of lower-carbon steels is superior to that of higher-carbon steels when both are quenched entirely to martensite (fully hardened) and tempered to the same hardness, notch-toughness being measured by Charpy keyhole-notch impact tests at room temperature. Average Charpy value for such steels as a class may be computed from the equation:—

$$\text{Charpy value (ft.-lb.)} = 79 \cdot 0\text{-}1 \cdot 08 \text{ Rockwell C hardness} - (29\% \text{ carbon})$$

'(2) The same conclusion may be expressed in terms of the tempering temperature required to produce the desired hardness: tempering at a relatively low temperature (lower-carbon steels) is superior to tempering at the higher temperature required to soften higher-carbon steels to the same extent.

'(3) In room-temperature tests, notch-toughness was lower after tempering at 600°F. (315°C.) than after tempering at a somewhat lower or a higher temperature, as has been shown by others. Refrigeration at −320°F. (−196°C.) before tempering apparently transformed retained austenite present after quenching, as indicated by changes in density, but did not affect notch-toughness after subsequent tempering. This evidence indicates that relatively low notch-toughness after tempering at 600°F. is not caused by retained austenite.

'(4) When tested at lower temperatures, the effect of tempering temperature on notch-toughness was even greater in many instances than in room-temperature tests. In general, notch-toughness after tempering at 600°F. was lower than after tempering at 450°F. (232°C.) or at 700°F. (371°C.), at all test temperatures except the highest and lowest ones investigated.

'(5) The relatively small number of tests made over a wide temperature range indicate that steels containing 0·3 per cent. carbon are tougher at all temperatures tested than steels containing 0·4 per cent. carbon tempered to the same hardness.'

Sub-Zero Tensile and Fatigue Properties of Nickel-Alloy Steels

J. W. SPRETNAK, M. G. FONTANA and H. E. BROOKS: 'Notched and Unnotched Tensile and Fatigue Properties of Ten Engineering Alloys at 25°C. and −196°C.' *Trans. Amer. Soc. Metals*, 1951, vol. 43, pp. 547-70.

The work covered by this paper is a sequel to that reported in *Trans. Amer. Soc. Metals*, 1949, vol. 41, pp. 480-518; for abstract see *Nickel Bulletin*, 1948, vol. 21, No. 11, pp. 165-6. The first series of tests included determinations of sub-zero properties of aluminium- and magnesium-base alloys, aluminium bronze, a low-alloy nickel-chromium-molybdenum

steel, austenitic nickel-chromium steels, and an 8½ per cent. nickel steel.

The object of the work described in the present paper was the assessment of the effect of notches, on tensile and fatigue properties, at room temperature and at -196°C. The materials studied were the following types: aluminium- and magnesium-base alloys, S.A.E. 2330 nickel steel, low-alloy (8630) nickel-chromium-molybdenum steel, stainless steel (Type 304), titanium, nickel-manganese-molybdenum steel (Hy-Tuf), and nickel-chromium-molybdenum (S.A.E. 4340) steel. Vickers hardness and Charpy key-hole impact tests were also made on all the materials, at room temperature and at temperatures down to -253°C. (For detailed descriptions of the experimental technique used reference is directed to the earlier paper).

From the results of the individual series of tests (reported in full detail) the following general conclusions are drawn:

'(1) In the unnotched tensile tests, the modulus of elasticity, yield strength, ultimate strength and nominal fracture stress all increase with decreasing temperature. Ductility values show an erratic dependence on temperature.

'(2) The effect of a notch is to increase the ultimate strength in tension, which also increases with decreasing temperature. Notches decrease fracture stress, however, both at 25°C. and at −196°C.

'(3) In the unnotched fatigue tests, the following average increases in fatigue strength at −196°C., over that at 25°C., occurred: 55% for 10^7 cycles, 45% for 10^5 cycles, and 38% for 10^4 cycles.

'(4) With regard to notched fatigue tests at 25°C. and −196°C. the following conclusions are drawn:

'(*a*) The average decreases in fatigue strength at 25°C. caused by the presence of the notch are: 64% for 10^7 cycles, 45% for 10^5 cycles, and 26% for 10^4 cycles.

'(*b*) At the endurance limit (10^7 cycles), the non-ferrous alloys and steels heat-treated to 230,000 p.s.i. (102·5 tons per sq. in.) tensile strength are least sensitive to notches at 25°C. and −196°C.

'(*c*) In the case of overstressing (10^4 and 10^5 cycles), the steels treated to 150,000 p.s.i. (67 tons per sq. in.) tensile strength show the least notch sensitivity at 25°C. However, at −196°C., the least notch sensitivity is exhibited by the non-ferrous alloys.

'(*d*) Steels treated to 230,000 p.s.i. tensile strength are superior to those treated to 150,000 p.s.i. tensile strength only for 10^7 cycles. In the case of overstressing, the steels at the lower strength-level have superior resistance to notches.

'(5) Vickers hardness increases with decreasing temperature. Sharp increases were noted in the following cases: (*a*) 18-8S stainless steel, −78°C. to −196°C. (*b*) Hy-Tuf steel, −196°C. to −253°C. (*c*) S.A.E. 4340 steel at both strength levels, −196°C. to −253°C.

'(6) In general, impact strength shows an inverse relationship to notch-sensitivity, and it is therefore concluded that impact strength is not a reliable criterion for notch-sensitivity in fatigue at low temperatures.'

Properties of Nickel-containing Materials in Intermediate Elevated Temperature Range

See abstract on p. 158.

HEAT- AND CORROSION-RESISTING MATERIALS

Creep of Metals: Creep-Resistant Materials

L. ROTHERHAM: 'Creep of Metals.' *Published by Inst. Physics, in 'Physics in Industry' series*, 1951; 80 pp.

This monograph, by a member of the staff of the Royal Aircraft Establishment, Farnborough, is written 'from the point of view of one who has spent many years in the study of engineering creep-resistant alloys.' In view of the volume of literature on this subject, and the need for compression into a relatively short treatise, the author has worked on a highly selective basis, referring only to those publications which he considers to have been of the greatest value in the course of industrial research. The *bibliography* thus chosen contains reference to over 80 original papers.

The treatment of the subject is essentially fundamental, dealing with the characteristics of the creep curve, crystalline flow, metallographic features of creep, grain-boundary creep, transient and steady-state creep, and tertiary creep. The final chapter contains a highly condensed discussion of the nature of creep-resistant alloys, relating structure and composition to creep characteristics. The discussion is illustrated by reference to high-temperature alloys typical of the nickel-, cobalt-, and iron-base groups.

In conclusion, the author points out that 'the development of creep-resistant materials has mainly been the work of metallurgists, while the general theory of creep has been developed by physicists. There is a large field of study on the structural aspects of creep between these two extremes, which is largely unexplored, and in which both metallurgists and physicists are showing interest'. Lines of research which could profitably be followed are suggested.

Nickel Conservation Orders

See abstract on p. 148.

Sigma Formation in Heat-Resisting Nickel-Chromium Steel

A. E. BINDARI, P. K. KOH and O. ZMESKAL: 'Sigma-Phase Formation in a Wrought Heat-Resisting Steel.' *Trans. Amer. Soc. Metals*, 1951, vol. 43, pp. 226-36; disc., pp. 236-42.

Previous investigators have concluded that steel of the following type analysis is immune from susceptibility to sigma formation:— carbon 0·12 max., chromium 18·5-19·5, nickel 8·5-9·0, tungsten 0·5-1·5, molybdenum 0·2-0·5, niobium 0·25-0·5, titanium 0·15-0·40, per cent.

The present authors, after a résumé of the evidence on which such conclusion has been based, report experimental work demonstrating that it is possible for sigma phase to be formed in such steels, on prolonged exposure within certain temperature ranges. Specimens of the steel were subjected, in both the annealed and the strain-hardened conditions, to periods of

exposure varying from 0·1 to 3500 hours, at the following temperatures: 1400°, 1500° and 1600°F. (760°, 815° and 870°C.). Rate of formation of sigma was extremely slow in the annealed steel, but much more rapid in steel which had been strain-hardened to an extent which would come within the range of working produced by hot-mill practice. Examination of the structural changes was made by measurement of magnetic intensity, etching tests (oxalic acid, used electrolytically), and X-ray analysis. Micro-hardness determinations were also made, using a Knoop hardness tester.

Correlation of the data obtained by the above methods is considered to justify the following conclusions:—

(1) Sigma forms in sites formerly occupied by ferrite stringers in the duplex austenite-ferrite structure. This phase grows continuously, reaching a maximum after about 1400 hours and thereafter decreasing. Its formation is accompanied by a decrease in magnetic susceptibility of the steel.

(2) Precipitation of carbides from ferrite occurs within a short time, but with prolonged time of ageing these carbides, with the exception of highly refractory types, are completely dissolved in the austenite.

(3) There is some indication that during ageing at 1400°-1600°F. there occur:—

(*a*) a high rate of transformation of some of the ferrite to austenite.

(*b*) a low rate of transformation of the remaining ferrite and newly formed austenite to sigma.

(4) The results demonstrate the major importance of strain hardening as a factor increasing rate of formation of sigma in this type of steel.

Sigma Phase in Nickel-Chromium-Molybdenum Steel containing Titanium

C. H. COOKE: 'The Occurrence and Some Effects of the Sigma Phase in a Molybdenum-bearing Stainless Steel containing 1% Titanium.' *Australasian Engineer*, 1950, Aug. 7, pp. 80-90.

The author reports investigations on a steel of the following composition: carbon 0·06, silicon 0·84, manganese 0·88, nickel 7·85, chromium 17·47, molybdenum 2·88, titanium 1·10, per cent.

Water-quenched specimens of the steel were reheated to various temperatures in the range 600°-900°C., for times varying up to 4 hours, and the alterations brought about by such exposures were studied by determination of changes in magnetic properties, mechanical properties, microstructure and corrosion-resistance. In addition, samples which had been re-heated to these intermediate temperatures were re-softened by the normal softening treatment (1150°C. for ½ hour and water-quenching) and the effects of such treatment were studied.

The results (reported in extenso) confirm that sigma formation occurs under the conditions investigated, and that such structural change is associated with deterioration in mechanical and physical properties, and, in some conditions, with lowered corrosion-resistance. It is urged, however, that, from a strictly practical point of view, susceptibility to sigma formation in this type of steel is not often dangerous, since, if the steel is properly heat-treated, formation of sigma does not occur, and the applications for which this steel is most suitable, and in which it is most frequently used, do not involve exposure to temperatures within the dangerous (sigma-forming) range. A considerable tonnage of 18-8-Mo-Ti steel has been in chemical-plant service for several years, and, so far as the author is aware, no records of failure by corrosion have been attributable to occurrence of sigma.

Nickel-containing Materials in Gas Turbines for Aircraft

'Ten Years Progress in Gas-Turbine Metals.' *Aeroplane*, 1951, vol. 80, May 11, pp. 585-6.

A review of some of the contributions made by high-temperature materials to the progress of aircraft propulsion. The pre-war background and the stage of development which had been reached in 1938 are briefly reviewed, followed by notes on some of the most important materials which were developed during the 1939-1945 period, e.g., the Nimonic series, G.18B steel, Red Fox 33, and ferritic steels of the Hecla 153, Hykro V 80, and related types. Future trends in materials for gas turbines are also noted, with due regard to availability of the various metals required, development of sintered alloys, and the use of non-metallic materials.

Nickel-Chromium Brazing Alloy

'New Brazing Material Shows Promise.' *Nickel Topics*, 1951, vol. 4, No. 4, p. 3.

The article describes the use of 'Nicrobraz' (nickel 65-75, chromium 13-20, per cent., plus boron), an alloy which has been developed, by Wall Colmonoy Corporation, for brazing the austenitic and straight-chromium stainless steels, alloys of the S-590 and Vitallium types, high-nickel alloys, alloy and tool steels, and metal carbides. The alloy has an original hardness of about Rockwell C 60 and its melting range begins at 1850°F. (1008°C.). It flows readily at 1900°F. (1036°C.) in a pure dry-hydrogen atmosphere. Tests reported in this article show that joints made with 'Nicrobraz' retain their strength and resist oxidation after heating for long periods at 1500°F. (815°C.).

Properties and Uses of Nickel-containing Heat-Resisting Alloys

HENRY WIGGIN AND CO., LTD.: 'High-Nickel Alloys for Heat-Resisting Equipment.' **Publn.* 295, 1951; 21 pp.

The combination of mechanical strength and oxidation-resistance characteristic of high-nickel alloys has for many years been utilized in a variety of applications. Choice among these alloys, for specific uses, is dictated by (1) the operating temperature, (2) the mechanical and thermal stresses imposed in service, and (3) the atmosphere in which the equipment is to be used. In the light of these variables, this publication reviews the properties and uses of the following materials:—

Nimonic 75: essentially an alloy of the 80-20 nickel-

* *We shall be pleased to supply a free copy of this publication.*

chromium type, with small additions of other elements.

Inconel: nominal composition nickel 76, chromium 15, per cent., balance iron.

Nimonic D: nominal composition nickel 37, chromium 18, per cent., balance iron.

Malleable Nickel: 99 per cent. nickel min.

Mangonic: nickel 96, manganese 2·5-3·5, per cent.

The resistance of the respective materials to various heating conditions (sulphur-free and sulphur-containing atmospheres, and controlled atmospheres) is reviewed, and typical physical and mechanical properties, at room temperature and at elevated temperatures, are tabulated. The elevated-temperature data include information on creep and fatigue characteristics, as well as short-time tensile properties.

Typical applications of the alloys are discussed (with illustrations), in sections relating to conveyor belts; furnace rollers; muffles; furnace tubes; covers of bell furnaces; nitriding furnaces; carburizing boxes; heat-treatment containers; baskets, trays and trolleys used in furnaces, kilns, etc.; pins for element supports in furnaces; thermocouple tubes; cores, and die inserts. In each case an indication is given of the individual type of alloy to be preferred for the respective applications.

Although the review deals primarily with the properties and uses of wrought materials of the types mentioned, it is noted that in some cases cast nickel-chromium-base alloys are more economical than wrought forms. Castings also are produced in a variety of nickel-containing heat-resisting materials.

Properties of Nickel-containing Materials in the Intermediate Elevated-Temperature Range

J. F. ERTHAL: 'Navy Studies Jet Structural Alloys at Intermediate Temperatures.' *Iron Age*, 1951, vol. 167, May 10, pp. 91-5.

The paper reports an investigation of the properties of S.A.E. 4340, Inconel 'X', and Stainless 'W' steel, heat-treated to ultimate tensile strengths of 200,000 to 220,000 p.s.i. (89-98 tons per sq. in.), a range which, it is anticipated, will be required in materials used in piloted and unpiloted aircraft operating at high speeds. Composition of the three materials is shown below:—

Chemical Compositions

Material	C %	Mn %	S %	P %	Si %	Ni %	Cr %	Fe %	Ti %	Nb %	Al %	Cu %	Mo %
Inconel 'X' ..	0·05	4·45	0·006	—	0·42	72·20	14·18	6·95	2·36	1·11	0·86	0·10	—
Stainless 'W' ..	0·07	0·52	0·009	0·024	0·56	6·56	16·87	—	0·51	—	0·15	—	—
S.A.E. 4340 ..	0·37	0·60	0·021	0·014	0·21	1·75	0·74	Bal.	—	—	—	—	0·23

Mechanical properties, impact and hardness values, and fatigue characteristics were investigated at room temperature, (1) prior to high-temperature exposure, and (2) after exposure, for various periods, at 700°F. (371°C.) and 900°F. (482°C.). In addition, stress-rupture, creep, and endurance characteristics were determined at 700° and 900°F.

The data so obtained are shown in a series of graphs, tables and photomicrographs. The following conclusions are drawn:—

Exposure to the (intermediate) high temperatures caused little or no change in the room-temperature properties of Inconel 'X'. The tensile and yield strengths, and the hardness of Stainless 'W' were progressively increased with time of exposure, such changes being accompanied by fall in impact strength and ductility. In the S.A.E. 4340 steel there was progressive fall in tensile and yield strengths, but little change in impact strength and ductility. The Charpy impact values of aged Stainless 'W' at 700°F. showed a clearly marked increase over the corresponding room-temperature values.

The decreasing order of merit, with respect to rupture and creep strength, is Inconel 'X' at 900°F., Stainless 'W' at 700°F., S.A.E. 4340 at 700°F. It is anticipated that Inconel 'X' would occupy an increasingly favourable position with respect to resistance to rupture and creep at 700°F.

At 700°F. Stainless 'W' shows a greater resistance to reversed-bending fatigue than S.A.E. 4340. Valid comparisons cannot be drawn in this connexion with Inconel 'X', since the tests on that alloy were made at 900°F.

Metallurgy of Chromium Stainless Steels: Reference Data

H. THIELSCH: 'Physical and Welding Metallurgy of Chromium Stainless Steels.' *Welding Jnl.*, 1951, vol. 30, May, Suppl. pp. 209-50.

This review, prepared under the auspices of the Literature Advisory Committee of the Welding Research Council, is supplementary to the review of literature on the austenitic stainless steels (*ibid.*, 1950, vol. 29, Dec., Suppl. pp. 577-621; see *Nickel Bulletin*, 1951, vol. 24, No. 2, pp. 43-4).

Published and unpublished information made available by laboratories, research investigators and welding engineers has been correlated, analyzed, and interpreted, particular attention being given to European developments which resulted from a shortage of nickel and consequent increased application of straight-chromium and related stainless-steel types. The arrangement and scope of the review is indicated below: the information given is supported by a *bibliography* of 213 references.

I. Physical Metallurgy

Phase Relations (The gamma loop; ferritic stainless steels; martensitic stainless steels.)

Structural Phenomena Affecting Physical Properties '885°F.' (475°C.) *Brittleness* (Effects of exposure time and rates of cooling; influence of alloying elements;

influence of embrittlement on corrosion-resistance; distinguishing brittleness from sigma-phase precipitation; causes of embrittlement and means for removal; effect of welding in relation to embrittlement; effects of embrittlement in service applications)

Sigma-Phase Embrittlement (Rate of sigma formation; effects of alloying elements and of cold work; effects of sigma on mechanical properties and on weld deposits; solution of sigma)

High-Temperature Embrittlement (Influence of structure; effects of embrittlement on mechanical properties; causes and removal of embrittlement)

Notch-Sensitivity (Influence of chromium, carbon and nitrogen contents; fractographic analysis; influence of grain size, as a factor affecting applications of high-chromium steels, and as influencing design and forming operations; ductile-to-brittle transition)

Grain Size and Grain Growth

Effects of Elevated Temperatures and Hot Working

Stress Corrosion Cracking.

II. Effects of Alloying Elements

(Consideration of the individual effects of the following elements: aluminium, bismuth, carbon, chromium, niobium, hydrogen, manganese, molybdenum, nickel, nickel+molybdenum, nitrogen, phosphorus, silicon, sulphur, titanium, tungsten.)

III. Welding Chromium Stainless Steels

(Use of austenitic welding electrodes; effects of the welding process on structure and properties; welding of the fully and partially martensitic grades, using fully or partially martensitic electrodes, or austenitic electrodes; welding of the ferritic grades, with ferritic or with austenitic electrodes; welding of high-chromium ferritic stainless-steel castings.)

Effect of Shot-Peening on Fatigue Strength of Austenitic Nickel-Chromium Steel

W. E. BARDGETT and F. GARTSIDE: 'Shot Peening. Effect on Fatigue Properties of 18-8 Chromium-Nickel Steel.' *Iron and Steel*, 1951, vol. 24, June, pp.195-7.

Failure, by fatigue, of austenitic-steel strainer plates used in a paper-pulping machine led to investigation of the effect of shot-peening as a means of enhancing fatigue-resistance. This note reports the results.

On the basis of rotating-cantilever tests, light shot-peening improved the limiting fatigue stress of the steel by 11 per cent. in specimens 0·30 in. in diameter and by 46 per cent. in specimens 0·14 in. in diameter. Still greater improvement would probably be effected by shot-peening sheet less than 0·14 in. thick, although in very thin material there would be a limit to the possibility of treatment, in order to prevent over-peening and reduction due to surface weakening.

Optimum increase in fatigue strength was obtained on 0·14-in. diameter specimens with shot-peening times of 15 and 30 seconds. The structure of the steel near the surface showed little evidence of dislocation when exposed to shot for periods up to 60 seconds. The surface was roughest after 15 seconds' exposure; prolongation of peening reduced the roughness.

Sub-Zero Tensile and Fatigue Properties of Nickel-Alloy Steels

See abstract on p. 155.

Resistance of Nickel-containing Steels to Hydrogen, Nitrogen, and Carbon Monoxide

G. A. NELSON: 'Metals for High-Pressure Hydrogenation Plants.' *Trans. Amer. Soc. Mechanical Engineers*, 1951, vol. 73, Feb., pp. 205-11; disc., pp. 211-13.

The paper is based mainly on experience in the plants of the Shell Development Company, in the processing of hydrogen-gas mixtures. The nature of the attack imposed by *hydrogen* at high temperatures and pressures is discussed, with examples of the effects produced on carbon and low-alloy steels. Attack by hydrogen is prevented by adding to the steel any of the carbide-stabilizing elements: in ascending order of potency they are manganese, molybdenum, chromium, tungsten, vanadium, titanium and niobium. All the austenitic steels are highly resistant to attack, due to the considerable percentage of chromium present. The non-carbide-forming elements, such as nickel and silicon, have no influence in this respect: phosphides and sulphides tend to increase susceptibility to attack.

A chart, compiled from the operating experience of various companies, shows limiting conditions for use of low-carbon, 0·5 per cent. molybdenum steel, and various types of chromium-molybdenum steel, in contact with hydrogen at high temperatures and pressures. The behaviour of the respective types is critically discussed.

Experience in the Shell plants indicates that when *sulphur* is present, either as the element or as hydrogen sulphide, it has the ability to corrode either carbon steel or low-chromium steel when the temperature rises above 675°F. (355°C.). In some cases a chromium-molybdenum steel (5/0·5 per cent.) has proved adequate, but it has been found that for complete resistance to sulphide attack the more-highly-alloyed steels, such as 12 per cent. chromium or 18-8, are required.

Where *nitrogen is present with hydrogen* nitriding has been found to occur at temperatures above 850°F. (455°C.) in ammonia plant operating at 2140 p.s.i.: it is observed on steels containing more than 2 per cent. chromium, and austenitic steels are similarly affected. From a practical point of view the results of nitriding have not been dangerous; piping and heavy forgings have never failed from this cause. It is considered, however, that further information on resistance to hydrogen-nitrogen mixtures should be obtained, since thin components such as bellows, gaskets, heat-exchanger jackets, etc., cannot operate efficiently with a hard brittle surface layer. Tests are therefore in progress to determine the resistance, to this type of attack, of the following materials: Inconel, Hastelloys B and C, 35-15 nickel-chromium-iron alloy, and some of the high-temperature alloys developed for gas-turbine parts. For protection against nitriding an alloy containing chromium 16, nickel 15, silicon 3, carbon 0·4, per cent., has been found satisfactory, and the author reports that a 57-12 per cent. nickel-chromium-iron alloy containing 1·7 per cent.

tungsten is used for converters in the Claude process for synthetic production of ammonia.

Discussion of attack by *carbon monoxide-hydrogen* mixtures is based on reports of experience in Germany. Pilot-plant data compiled in the I.G. Farbenindustrie show, in chart and tabular form, the behaviour of manganese bronze, high-chromium steels, austenitic nickel-chromium steels, high-manganese steel containing 2 per cent. chromium, and low-carbon steel, when exposed, in various conditions of temperature and pressure, to a 50-50 mixture of carbon monoxide and hydrogen. The information obtained leads to the conclusion that the mixture is highly corrosive to ordinary constructional materials at high pressures when the temperature is between 300°F. (150°C.) and 650°F. (345°C.). In this range high-chromium or austenitic nickel-chromium steels or alloys must be used.

Resistance of Nickel-containing Materials to Ferric Chloride

'Materials of Construction vs. Ferric Chloride.' *Chemical Engineering*, 1951, vol. 58, May, pp. 244, 246, 248, 250-1.

The behaviour of the following materials in contact with ferric chloride is reviewed: stainless steel, Worthite, nickel and nickel alloys, rubber, cements, aluminium, high-silicon irons, Durimet 20, carbon and graphite, Chlorimet alloys, glass, Hastelloy alloys, wood, organic coatings, tantalum, silicones.

Stainless Steels are particularly susceptible to corrosion by ferric chloride; even Types 316 and 317, although more resistant than the other grades, are not dependable in service. Attack of the austenitic steels is characterized by random penetration of the surface by pitting, followed by rapid complete perforation. Rate of corrosion accelerates with rise in temperature. Solutions of ferric chloride tend to hydrolyze on standing, forming hydrochloric acid, which hastens and accentuates attack.

Worthite is not a commercially suitable material for handling ferric chloride, although it is safely used in contact with some solutions of low concentration.

Nickel and Nickel Alloys. Nickel, Monel, Inconel and the Ni-Resist cast irons are rapidly attacked by ferric chloride, except in very dilute solutions, e.g., containing less than 0·5 per cent. $FeCl_3$, at atmospheric temperatures. They have found application in equipment handling some effluents from the ferric-chloride treatment of sewage, where the residual content of ferric chloride is of the order of 0·2-0·3 per cent. Concentrated ferric-chloride solutions are used for decorative etching of the high-nickel materials, due to the rapidity of attack.

Durimet 20 is not recommended for handling ferric chloride at any concentration normally encountered.

Chlorimet Alloys can be used only with extreme care. Chlorimet 2 is definitely unsuitable, but Chlorimet 3 (containing chromium) shows good resistance to many ferric-chloride concentrations at normal temperature. Tests under conditions simulating service are, however, strongly recommended before using the alloy in this type of solution. Rise in temperature has a markedly intensifying effect on attack, and the presence of hydrochloric acid in ferric chloride is capable of producing corrosion even in relatively dilute solutions.

Hastelloy Alloys. Hastelloy C shows excellent resistance at moderate temperatures, over a range of concentrations, and the presence of oxidizing acids with the ferric chloride does not essentially change the degree of resistance. Additions of hydrochloric acid do not increase attack beyond what would be caused by the acid alone. Hastelloy C has been successfully used for pumps, pipes and other parts handling ferric chloride of various concentrations. At temperatures above about 70°C., however, the rate of corrosion tends to become erratic, and pitting is sometimes encountered.

Nickel-Chromium Corrosion-Resisting Steels in the Petroleum Industry

M. E. HOLMBERG: 'Experience with Austenitic Steels in High-Temperature Service in the Petroleum Industry.' *Amer. Soc. Mechanical Engineers, Paper* 50-*A*-41, Nov.-Dec., 1950; 7 pp.

The purpose of the paper is to call attention to factors which should be given primary consideration in selecting austenitic steels for high-temperature service in the petroleum industry. The facts given and opinions expressed are based on performance of materials in service and examination of parts removed from plant.

The importance and inter-relationship of high-temperature strength and resistance to creep are, the author considers, well recognized, and a considerable volume of data exists on this aspect of the subject. It is therefore not discussed at length in this paper. It is urged, however, that more careful consideration be given to certain other factors which affect service behaviour, e.g., high-temperature abrasion-resistance, also that it must be recognized that for many applications the use of stabilized grades of austenitic steel is unnecessary and uneconomic. Examples are quoted of service conditions in which *either* (1) unstabilized steel could have withstood the conditions as well as the stabilized grades used, *or* (2) a stabilized grade was as incapable of withstanding conditions as an unstabilized grade would have been. It is also suggested that even where temperature of service and corrosive conditions are such as to make stabilized steels desirable, it is often preferable to secure the stabilization by heat-treatment rather than by modification of composition. In this connexion the possibility of sigma formation is not overlooked, but the author contends that, from a practical standpoint, this is unimportant: 'Sigma phase has been observed in 18-8 and 25-20 chromium-nickel steels for 10 years and no mechanical failure has been observed in austenitic steel that could be attributed to sigma phase.'

Stress-relief treatment is, in general, to be deprecated for the austenitic nickel-chromium steels: it does not improve their properties, and may have an adverse effect on carbide precipitation, resulting in lowered corrosion-resistance, to a degree which may render the steel unfit for use. If stress-relief treatment must be applied, treatment at 1550°-1650°F. (842°-898°C.) is advocated, e.g., 8 hours at 1525°F. (830°C.)

or 2 hours at 1650°F. (898°C.). This treatment has proved satisfactory for steel used in oil-industry applications.

A further factor of importance in securing satisfactory service is adequate recognition of the expansion and contraction characteristics of austenitic steels. Unless correct allowance is made, failures, e.g., by stress-corrosion cracking, may occur.

Due regard must also be paid to the fact that the austenitic steels have a hot-short range between about 1000° and 1800°F. (538° and 980°C.) and that above about 2200°F. (1205°C.) they are extremely hot-short. Such limitations call for consideration in heating of pipe and other shapes for bending, and in other hot-working operations.

The low thermal conductivity of these steels (about one-fourth that of ferritic steel) results in steep temperature gradients, and uneven heating may cause hot spots which tend to be localized, leading to warpage and other undesirable effects. The low thermal conductivity and high coefficient of expansion of the austenitic steels are also responsible for poor resistance to thermal-shock and thermal-fatigue conditions present in many cyclic processes. The mechanism of this type of failure is discussed in relation to effects observed in a service installation, and tests used to determine the relative susceptibility of various types of steel to thermal shock and thermal fatigue are described.

Stainless-Clad Steel in the Petroleum Industry

J. ERSKINE: 'Application of Clad Steels in the Petroleum Industry.' *Brit. Petroleum Equipment News*, 1951, vol. 2, No. 1, pp. 27-30.

The current programme for construction, in the United Kingdom, of several large oil refineries has aroused widespread interest in the special types of plant which have already been developed (mainly in the U.S.A.) for this purpose. Among the materials of construction which are important in this connexion are the clad steels: for example, stainless-clad is being extensively employed in distillation units designed to deal with sour crudes.

Many of the manufacturing processes by which the clad steels are made have originated in the U.S.A., but this article deals specifically with the method patented by Messrs. Colvilles, Ltd. (*Brit. Pat.* 621,089). Diagrams illustrate a step-by-step description of the essential features of the process by which the clad plates are prepared, and photomicrographs demonstrate the nature of the bond obtained. Some of the test methods used to assess the efficiency of the bonding and the properties of the clad material are reviewed. Four grades of 'Colclad' are now in regular supply: 18-8-Ti, 18-8-Nb, 18-10-Nb and 14 per cent. Cr.

Although the stainless-clad steels consist of two different materials, in hot-pressing and hot-spinning operations the composite behaves as a solid plate; deep-drawn and hot-pressed parts are shown, to illustrate the workability of the materials. Notes are added on procedure for gas-cutting and for welding of stainless-clad steel.

Nickel and Nickel Alloys in Fluorine-Control Equipment

G. E. ZIMA and R. N. DOESCHER: 'Materials for Fluorine Control Equipment.' *Metal Progress*, 1951, vol. 59, May, pp. 660-3.

This article, which comes from the Jet Propulsion Laboratory, California Institute of Technology, covers one phase of research carried out there for the U.S. Army Ordnance Department.

It is pointed out that although some useful information on the industrial applications of fluorine has been published (see, for example, *Ind. Engg. Chem.*, 1947, vol. 39, pp. 1389-93), but little is at present known of the handling of liquid and gaseous fluorine under high-pressure conditions. This article adds to data available on this aspect of the subject.

Successful and safe handling of fluorine is dependent on careful selection of construction materials and the observance of unusual precautions to assure that equipment is free from contamination. At pressures around 600 p.s.i. liquid fluorine presents unique handling and control problems. A reaction between liquid fluorine and circuit contaminants, or between liquid fluorine and unsuitable construction materials, frequently results in ignition of the container metal contiguous to the reaction zone. Nickel and several high-nickel alloys have, however, demonstrated excellent resistance to both gaseous and liquid fluorine, and have made possible safe handling over a wide range of temperature and pressure. This article describes fluorine-control apparatus used at the California Institute, in which various types of nickel-containing materials are used. The individual components of the system are described, with illustrations, and service experience with regard to materials of construction is reported. Some of the observations made are briefly summarized below:—

Equipment Handling Liquid Fluorine

Tank. The low boiling point of fluorine (−187°C.: −305°F. at a pressure of 1 atmosphere) and its hazard potential dictate close temperature control of storage and feed systems. In the storage tank described, the liquid-fluorine container was originally made of nickel, and when moisture was removed from the tank prior to introduction of the fluorine no corrosion was experienced, but in the presence of water appreciable nickel-fluoride deposits were formed. On the basis of subsequent experience, it is concluded that nickel is inferior to Monel for this purpose, due to its lower resistance to attack by hydrofluoric acid, exposure to which is difficult to avoid in a fluorine system.

Piping. Here also nickel was originally used, but service results have indicated that Monel is to be preferred. Monel is also used in other parts of the feed line, and 'K' Monel flanges have proved suitable. 'K' Monel shows the same excellent resistance to fluorine as Monel; in neither 'K' Monel nor 'Z' nickel has the age-hardening treatment adversely affected corrosion-resistance. All welding in the unit was done with Monel 130 X electrodes, but later a Heliarc rod was developed for welding Monel, and is considered to be preferable. Both types of weld have

corrosion-resistance equal to that of the parent alloys.

Valves. Two critical points in the valves are the seating surfaces and the valve-stem packing. Complete shut-off for working pressures up to 800 p.s.i. has been achieved by seating 2S aluminium alloy against Monel: an aluminium-alloy insert was shrink-fitted into the Monel pintle, to provide the seating face. The most satisfactory form of primary valve-stem packing has been found to be a compact composed of flake graphite, powdered nickel and acid-treated shredded asbestos. 'S' Monel was used in the piston housing, being chosen on account of its anti-galling characteristics. Its resistance to high-pressure gaseous fluorine appears to be equal to that of Monel.

Flowmeter. A diagram of the rolling-ball type of flowmeter which has satisfied requirements shows the use of Monel for the jacketed housing, and outlet adapter, 'Z' nickel for the retainer component, ball race, and orifice plate, and Monel for the inlet adapter.

Equipment Handling Gaseous Fluorine

In handling gaseous fluorine the experience of the California Institute is that 'nickel and Monel are far in advance of other materials in meeting all requirements'. These two materials are used exclusively in the gas-phase system between the electrolytic cell and the condenser. From qualitative examination of equipment, it is concluded that nickel and Monel have performed equally well under similar operating conditions. 'The excellent resistance of Monel to hydrogen fluoride over a wide range of concentrations and temperatures, in addition to the superior mechanical properties achieved relative to nickel, recommends Monel as a general construction material for gaseous-fluorine equipment. The gaseous-fluorine environments presented by the installation at this laboratory have fortunately been confined to low pressures and moderate temperatures. Even under these conditions, however, the advisability of restricting construction materials to Monel has been demonstrated.'

Corrosion Problems in Transport Aircraft: Use of Stainless Steel

O. E. KIRCHNER and F. M. MORRIS: 'Corrosion Problems Related to Air Transport Aircraft.' *Corrosion*, 1951, vol. 7, May, pp. 161-77.

This paper, presented in 1950 before the National Association of Corrosion Engineers, is written by two members of the engineering staff of American Airlines, Inc. It gives a succinct review of corrosion problems arising in air transport aircraft, their causes, and methods which may be used to reduce corrosion to a minimum.

Sources of corrosion considered include exhaust gases and deposits containing lead bromide and free bromide, spillage of food and liquids in the buffet areas, leakage and splashes in the lavatory areas, general atmospheric and soil conditions, and waters of high chloride and sulphate content. The forms of attack resulting from these causes are reviewed seriatim, and the choice of material, design and treatment found to reduce corrosion to a minimum is discussed from an essentially practical angle. In view of the extensive use of aluminium-base materials in aircraft, much of the discussion centres on these alloys and on the magnesium alloys. Particulars are also given of the use of stainless steel in lavatory compartments and other parts subject to particularly corrosive conditions. Much importance is attached to correct design, proper heat-treatment (of aluminium alloys), suitable surface coating of parts, and correct cleaning procedures.

Atmospheric-Exposure Tests on Nickel-Chromium Steel Wires

AMER. SOC. TESTING MATERIALS: 'Report of Committee A-5 on Corrosion of Iron and Steel.' *A.S.T.M. Preprint* 4, June, 1951; 19 pp.

Includes report of 1950 inspection of wire and fencing specimens of bare steel and zinc-coated wires, copper-covered and lead-coated wires, and wires of high-chromium and austenitic nickel-chromium steels. The specimens have now been exposed for about 14 years: for reference to locations of exposure, preparation and nature of specimens, etc., earlier reports should be consulted (*Proc. Amer. Soc. Testing Materials*, 1939, 1941, 1943, 1945, 1947 and 1949). Severe industrial, normal industrial, sea coast and rural atmospheres are represented in the test sites.

Stainless-Steel Sinks

J. C. MCCOMB: 'Fabricating Stainless Steel Sinks at Pride Manufacturing Co.' *Steel Processing*, 1951, vol. 37, Apr., pp. 172-4.

The article describes all the operations involved in production of sinks from sheet of Type 302 steel. Throughout the fabricating stages the sheet material is covered with Protecto-Mask, to prevent damage to the polished surface. Blanking, forming, Heliarc welding of bowl to top, grinding, finishing and polishing procedures are reviewed, with illustrations.

Nickel-containing Materials for Analytical Weights

P. H. BIGG and F. H. BURCH: 'The Stability of Analytical Weights, particularly in Chemical Laboratories.' *Brit. Jnl. of Physics*, 1951, vol. 2, May, pp. 126-31.

The National Physical Laboratory has, in connexion with its responsibilities for testing national, scientific and industrial standard weights, accumulated a not inconsiderable amount of general information, but little has been recorded, there or elsewhere, on the stability of weights in the contaminated atmospheres of chemical laboratories, in conditions of regular use. The investigation which forms the main subject of this paper was undertaken to obtain a reliable basis for judging the relative merits of weights under such conditions.

Following an introductory review of materials in use as weights, and their general characteristics and behaviour, an account is given of tests in which a representative group of weights (100 g.) were exposed, for two periods of three months each, over working benches in five different chemical laboratories around London.

The weights exposed were of the following types:—

Unplated: austenitic stainless steel (25-20 and 20-10 chromium-nickel types); 80-20 nickel-chromium alloy; brass.

Plated: brass plated with copper-silver-platinum, platinum, copper-silver-rhodium, rhodium, nickel-chromium. Various thicknesses of plating were used: in the platinum- and rhodium-plated specimens the coatings covered the range likely to be met with in the open market; for the nickel-chromium coatings the specification requirements issued to the producers were based on B.S. 1224; 1945.

Weights of the above types were exposed in both series of three-month trials: in the second period only, more-highly polished 25-20 chromium-nickel steel and 80-20 nickel-chromium alloy specimens were added.

Behaviour of the weights (assessed by examination on receipt from the manufacturers immediately prior to the first exposure period, between the two exposure periods, and after the second exposure period) was assessed on the basis of appearance and changes in mass. Magnetic measurements were also made, to determine to what extent the magnetic properties of the nickel undercoat in the nickel-chromium-plated specimens might affect the accuracy of results.

The following conclusions are drawn from a correlation of the results obtained in the co-operative exposures:—

'Under good atmospheric conditions, analytical weights of austenitic stainless steel (25% Cr, 20% Ni) and of non-magnetic nickel-chromium (80% Ni, 20% Cr) can be relied upon to be extremely stable. Good quality platinized brass weights have been known to be extraordinarily stable, and it is probable that rhodium-plated weights can be equally stable. In any particular case it should not be assumed without good evidence, however, that a given plated weight is satisfactorily stable for normal use, and the absence from within it of corrodible adjusting material is not sufficient evidence of stability. Plain polished or lacquered brass weights are unsuitable for laboratory standards. As for nickel-plated and gold-plated weights, there are a number of superior alternatives.

'In the corrosive atmospheres encountered in these experiments there was little to choose between the weights of austenitic stainless steel (25% Cr, 20% Ni), non-magnetic nickel-chromium (80% Ni, 20% Cr), and the plated weights having a nominal thickness of plating of about 0·015 mm. (0·0006 in.) or more; the highly-polished stainless-steel weights were, however, slightly superior. Brass weights coated with a 'flash' of platinum or rhodium were not very superior to weights of plain polished brass.

'Among the plated weights, the appearance of those plated with chromium over nickel deteriorated the least, but any superiority in stability of mass over that of weights having the same total thickness of plating of platinum on silver or rhodium on silver is only slight, and is offset by the magnetic properties of nickel.

'No reliable correlation was found between the different chemical characteristics of the individual laboratories and the changes in the weights of the various materials exposed in them.

'Owing to its high corrodibility, lead should on no account be used for the adjustment, to nominal mass, of screw-knob weights.

'While it is always advisable to avoid sharp edges on weights and to provide a fairly broad seating, this becomes most important when preparing weights for plating, owing to the difficulty of buffing in the neighbourhood of sharp edges without removing excessive amounts of metal.'

Thermal Conductivity of Nickel Alloys and Stainless Steel at Low Temperatures

See abstract on p. 151.

Welding of Stabilized Nickel-Chromium Steels: Titanium vs. Niobium as Stabilizer

D. W. MCDOWELL: 'Cost of Welding Stabilized Stainless.' *Metal Progress*, 1951, vol. 59, May, pp. 650-2.

The article is a summary of evidence in support of the use of titanium-stabilized nickel-chromium austenitic steel in preference to niobium-stabilized type, for welded construction. Excerpts from the literature which favour this conclusion are reviewed, and an account is given of comparative experiments made (by Titanium Alloy Manufacturing Division, National Lead Company) in the welding of titanium- and niobium-stabilized 18-8 (types 321 and 347, respectively). The experiments covered welding by both the inert-arc and metal-arc processes; details of procedure are recorded, quality of welds is discussed, and labour costs are assessed. The author concludes that 'titanium-stabilized sheet may be purchased and welded with superior welds at less expense than the cost of niobium-stabilized stainless sheet alone.'

Hard-Surfacing of Dies with Hastelloy 'C'

A. GRAY: 'Dies Hardfaced with Alloy Last Longer.' *Iron Age*, 1951, vol. 167, May 31, pp. 68-70.

During the past few years there has been an increasingly heavy demand for steel forgings containing relatively high percentages of alloy elements. Such steels must be worked at considerably higher temperatures and pressures than plain and lower-alloy steels, and rate of die wear is appreciably greater.

This problem has been solved in many cases by hard-facing the dies with a refractory alloy, and for this purpose Hastelloy 'C' has proved especially suitable.

Introduced as a facing during the war, for use on nosing and forming punches producing shell, it has subsequently been applied with much success for dies handling other types of product. This article gives some examples of the economies which have resulted from adopting the hard-facing procedure: three typical cases are cited below.

(1) The cutting edges of a trimmer handling spring-steel harrow teeth were of ordinary boiler-plate steel. When used in the bare condition such dies were considered to give good service if they trimmed 10,000 pieces before requiring re-sharpening. Hastelloy-faced dies have trimmed up to 60,000 pieces before needing re-sharpening. The spring-steel teeth are at a temperature of about 1600°F. (870°C.) when being trimmed.

(2) Sucker rods for oil wells are provided with square wrench fits for making adjustments during operation, and in forging the rods it is important that the wrench squares be uniform in size. Unfaced dies produced from 9,000 to 10,000 joints before they had to be scrapped, but when faced with Hastelloy 'C' were found to be capable of handling an average of 28,000-32,000 pieces. In this case temperature of forging is in the region of 2200°F. (1205°C.).

(3) An increase in service life of about 40 to 1 is reported as being obtained by hard-facing of a piercing punch used to produce holes in bushings of chromium-molybdenum nitriding steel. The punch had to be water-cooled, and the severe thermal shock caused chipping and spalling of steel punches after using about 100 times. Hard-faced punches can handle 3,000-4,000 pieces before re-surfacing is required.

Exposure Tests on Nickel-plated Steel Panels

See abstract on p. 149.

PATENTS

Electrolytic Production of Malleable and Annealable Nickel

Malleable and annealable nickel cathodes free from pits and 'berries' are obtained, in a Hybinette-type process, by using a nickel-sulphate plating solution free from lead, arsenic, and organic matter. The bath contains more than 25 g. nickel/litre; the preferred pH is 1·5-3·5. It is operated at 40°-80°C., with current density 0·5-5 amp./sq. dm., and the electrolyte in the cathode bag is agitated by means of fine air bubbles.

A. M. GRONNINGSAETER, assignor to FALCONBRIDGE NICKEL MINES, LTD. *Canad. Pat.* 473,608.

Nickel Catalysts

To produce alkalized foraminate catalysts an alloy containing aluminium and a catalytically active metal or metals is treated with an aqueous solution of caustic alkali, at an uninterrupted space velocity greater than 10, to remove a portion of the aluminium from the surface layers of the alloy and provide for the presence of free alkali in the catalyst prior to use. The alloy may be copper-aluminium (copper 40-80), nickel-aluminium (nickel 30-62), cobalt-aluminium (cobalt 15-55), or iron-aluminium (iron 30-55), all percentages by weight.

P. W. REYNOLDS, J. A. MACKENZIE and IMPERIAL CHEMICAL INDUSTRIES, LTD. *Brit. Pat.* 650,251.

Preparation of Nickel Carbonyl

The invention described is based upon the discovery that carbon monoxide under pressure reacts rapidly with a slurry of freshly precipitated hydrated nickel oxide containing a small amount of a complex mixture of sulphur compounds, which may be formed in situ by addition of a suitable sulphur compound to the slurry. The sulphur compounds incorporated may be an alkali or alkaline-earth sulphide or thio-sulphate, a mixture of the two, or a mixture which contains one or more of these substances, and an alkali or alkaline-earth sulphide.

In a related patent cyanide ions are used instead of sulphur compounds, as the catalyst.

J. F. KINCAID and J. S. STRONG, assignors to ROHM AND HAAS CO. *U.S. Pats.* 2,548,727 and 2,548,728.

Strengthening Porous Bodies of Nickel

Porous metallic bodies, as used for filters, fuel mixers, flame arresters and other applications, are strengthened, without lowering effective porosity, by impregnating the body with inert fluid (e.g., mineral oil), compressing, removing the fluid and sintering under reducing conditions. When treating nickel and tungsten bodies prior to impregnation, heating in hydrogen or hydrogen and a fluxing gas, e.g., SO_3, is recommended. The liquid material with which the mass is impregnated provides the hydrostatic pressure necessary to keep the pores of the body open, and also acts as a lubricant between the particles of the body and the die and ram, eliminating smearing of the surface of the particles. Bodies so treated are strengthened, while retaining a large proportion of 'unsealed' pores. Conditions suitable for treatment of nickel porous bodies are described.

W. W. BEAVER, assignor to BATTELLE DEVELOPMENT CORPN. *U.S. Pat.* 2,540,233.

Electrodeposition of Bright Nickel Coatings

To obtain bright or semi-bright deposits a thia-naphthene dioxide (0·04-1·0 g./L.) is added to an aqueous acid nickel-plating bath. The components of the bath may be selected from the group consisting of nickel sulphate, mixtures of nickel sulphate and nickel chloride, nickel fluoborate, and mixtures of nickel sulphate and nickel fluoborate.

P. W. MOY, assignor to HARSHAW CHEMICAL CO. *U.S. Pat.* 2,539,588.

Nickel Plating of Magnesium-base Materials

The patent covers preparatory treatment of magnesium or magnesium-alloy surfaces on which silver, nickel, cadmium, chromium or other metal is to be electrodeposited. The basis metal is immersed in an aqueous solution of one or more compounds selected from the group consisting of the soluble salts of zinc, cadmium and manganese, which are decomposed by magnesium to produce a metallic deposit. After such treatment the work is rinsed in boiling 10 per cent. chromic acid, and afterwards treated with an aqueous solution containing a compound of mercury. On surfaces so prepared the required final metal coating can be electrodeposited.

MAGNESIUM ELEKTRON LTD. and W. F. HIGGINS. *Brit. Pat.* 652,800.

Electroforming: Separating Media

In making a metal article by electrodeposition on a metal base (e.g., a gramophone-record pressing matrix

from a master matrix), separation is made easier by first coating the master with a thin film of albumen, casein, dextrin, gelatin, glue, or gum arabic, from colloidal solution, without subsequent chemical treatment. The method is applied to the deposition of nickel, silver, gold, or copper on a nickel base, and of nickel or copper on a copper base.

ELECTRICAL AND MUSICAL INDUSTRIES, LTD., and W. SOBY. *Brit. Pat.* 651,611.

Cyclic Electropolishing Process

In an acid bath for polishing iron, steels, nickel and electrodeposited nickel coatings the anode film thickness cyclically builds up and decreases, giving more rapid polishing and high current efficiency. Baths producing this effect consist of 40-65 per cent. of 66° Bé sulphuric acid, 5-20 per cent. of 26 per cent. aqueous fluoboric acid, and 25-55 per cent. water. The fluoboric acid may be used as the zinc or nickel salt, and oxalic acid may be added up to 130 g./gall., to produce a smooth finish and to stabilize the bath. The bath-temperature range is 48°-85°C. and current densities of 50-500 amp./sq. ft. at 4-9 v. are used, depending on the metal. Agitation of the anode is recommended. Preferred compositions are given

W. J. NEILL, assignor to COLUMBUS METAL PRODUCTS, INC. *U.S. Pat.* 2,542,779.

Nitric-Acetic Acid Electropolishing Baths

Stainless steel is electropolished in a concentrated acid bath containing nitric acid, preferably mixed with concentrated acetic acid, using alternating current. The treatment is carried out at a temperature below 25°C., preferably between −12°C. and +15°C.

ALLOY RESEARCH CORPN. *Brit. Pat.* 651,077.

Condenser-Tube Alloy

A copper-nickel alloy resistant to salt-water corrosion, and suitable for condenser tubes, contains nickel 2-20, iron 0·25-2, per cent., balance copper. Preferred composition is nickel 10, iron 0·75, per cent., balance copper.

A. W. TRACY and E. W. PALMER, assignors to AMERICAN BRASS CO. *Canad. Pat.* 473,750.

Columnar Nickel-Alloy Magnets

Alni or Alnico type magnets of improved magnetic properties are obtained by pouring the molten metal at a temperature of 1600°C. or above, into a metal or refractory mould heated to 600°-1200°C., and chilling one end of the mould while delaying cooling from the sides, to induce formation of columnar crystals along the casting. Alternatively, niobium and/or tantalum may be added, up to a total of 5-6 per cent., to retard setting, and the alloy is poured at 1500°C. (In this connexion see also *Nickel Bulletin*, 1950, vol. 23, No. 6, p. 107 and 1951, vol. 24, No. 5, p. 79.)

SWIFT LEVICK AND SONS, LTD., and G. D. L. HORSBURGH. *Brit. Pat.* 652,022.

Magnesium+Cerium Additions to Produce Spheroidal-Graphite Cast Iron

To produce hypoeutectic grey cast iron containing spheroidal graphite, magnesium is added to give a retained magnesium content of at least 0·015, but less than about 0·04, per cent. (insufficient in itself to produce spheroidal graphite), and sufficient cerium to produce a retained cerium content of at least 0·015 per cent. The iron is inoculated with 0·3 to 2·5 per cent. silicon, and cast to give a hypoeutectic grey casting having a magnesium+cerium content of 0·05-0·75 per cent. The graphite is present in a substantially spheroidal form.

A. P. GAGNEBIN and W. M. SPEAR, assignors to INTERNATIONAL NICKEL CO., INC. *U.S. Pat.* 2,542,655.

Sigma-Free Complex Austenitic Steels

Substantial freedom from sigma-phase formation under continuous exposure to high temperature is obtained in chromium-nickel steels containing carbon 0·09-0·20, chromium 15·75-16·75, nickel 13·25-14·75, molybdenum 1·75-2·8, copper 2·5-3·5, titanium 0·10-0·25, niobium 0·35-0·55, manganese 0·20-1·5, silicon up to 0·70, sulphur not more than 0·03, phosphorus up to about 0·12, per cent. The preferred ratio $\frac{2\,(\%\ \mathrm{Ti})+\%\ \mathrm{Nb}}{\mathrm{C}}$ is 5 to 10. Composition is critical, and preferred ranges are narrow. Either niobium (0·20-0·50 per cent.) or tantalum (0·60-0·90 per cent.) may be used in the absence of the other, at the same ratio to carbon. The load-carrying capacity at temperatures above 1500°F. (815°C.) is improved by solution+ageing treatment at specified temperatures.

W. C. CLARKE, assignor to ARMCO STEEL CORPN. *U.S. Pat.* 2,540,509.

Complex Austenitic Nickel-Chromium Steels

The patent covers nickel-chromium steels containing tungsten and/or molybdenum, for high-temperature uses such as gas-turbine blades. The composition range and preferred composition (in brackets) are as follows: nickel 5-30 (5-25), chromium 30-5 (30-10), carbon 0·08-1·0 (0·2-0·6), silicon 0·1-2 (0·2-1·5), manganese 0·1-5·0 (0·1-1·2), titanium 1·5-15 (2·0-8·0), cobalt 6-30 (6-30), nitrogen 0-0·3 (0·06-0·3), tungsten 0·05-10, molybdenum 0-15 (tungsten+molybdenum 1·5-10), per cent., iron above 30 per cent. The steels may also contain aluminium 0·03-30 or copper 0·05-15, per cent. The titanium is preferably introduced in a vacuum furnace or in a non-oxidizing atmosphere.

W. JESSOP AND SONS, LTD., D. A. OLIVER and G. T. HARRIS. *Brit. Pat.* 653,311.

Machinable Nickel-Chromium-Cobalt-base High-Temperature Alloys

High-strength heat-resisting alloys which are readily forged, welded and machined, and show good ductility at room temperature, contain chromium 15-25, nickel 2-25, cobalt 10-40, molybdenum up to 8, tungsten 0·5-15, manganese up to 2, silicon up to 1, carbon up to 0·35, nitrogen up to 0·25, per cent.,

with one or more of the elements niobium, tantalum, titanium and vanadium 0·5-3 per cent. (not more than 2 per cent. of any one, or more than 1·5 per cent. titanium), boron up to 1 per cent., aluminium up to 0·5 per cent. (boron+aluminium 0·01-3 per cent.), balance iron. Alloys containing nickel 10-15 and chromium 10-25 per cent. are claimed to have especially good machining properties.

R. FRANKS and W. O. BINDER, assignors to ELECTRO METALLURGICAL CO. *U.S. Pat.* 2,432,618.

Nickel-Chromium-Cobalt-base High-Temperature Alloys of Low Molybdenum Content

Alloys showing strength at high temperatures and good hot-working properties, suitable for gas-turbine parts, lie within the range carbon 0-1·5, manganese 0-1·5, silicon 0-1·5, nickel 30-40, chromium 18-24, cobalt 17-35, tungsten 4-8, niobium 2-6, nitrogen 0·10-0·20, per cent., balance iron.

Vanadium is equivalent to tungsten (1 part vanadium =2 parts tungsten). Molybdenum, which causes high-temperature embrittlement and lowers oxidation-resistance, is specified as not exceeding 1 per cent. Preferred range and optimum composition are given. Carbon and cobalt may be varied, provided that the percentage of cobalt is 120-160 times that of the carbon.

F. B. FOLEY, assignor to MIDVALE CO.
U.S. Pat. 2,543,841.

Stabilized Austenitic Weld Metal

Austenitic stainless-steel weld deposits characterized by good corrosion-resistance and freedom from sigma phase and carbide precipitation contain carbon up to 0·03, chromium 16-21, nickel 10-20·5, molybdenum 1·75-4, sulphur and phosphorus each not more than 0·02 per cent., balance iron. The ratio

$$\frac{\%\ \mathrm{Cr}+2\times\%\ \mathrm{Mo}}{\%\ \mathrm{Ni}} = \text{not more than about } 1\cdot50.$$

Manganese up to 2·5 per cent. or more may be present.

G. E. LINNERT, assignor to ARMCO STEEL CORPN.
U.S. Pat. 2,544,336.

Warm Working of Austenitic Steel Tubing

In a process for making tubes of a complex austenitic steel the final stages comprise a hot-drawing operation, followed by solution treatment which, in turn, is followed by warm-drawing, at 600°-900°C. The process is described as applied to tubing of a steel containing carbon 0·4, manganese 0·8, silicon 1, nickel 13, chromium 13, tungsten 2·5, molybdenum 2, niobium 3, cobalt 10, per cent.

W. JESSOP AND SONS, LTD., D. A. OLIVER and G. T. HARRIS. *Brit. Pat.* 653,318.

Nickel-Aluminium-base High-Temperature Alloys

Nickel-aluminium- and nickel-cobalt-aluminium-base alloys showing strength and creep-resistance at high temperatures contain nickel 54·00-81·74, aluminium 2·42-12·14, per cent. (weight ratio nickel: aluminium from 6 to 25:1), two addition metals from the group molybdenum, tungsten, tantalum, niobium 10-35 per cent., and other elements (not more than 2 per cent.) including not more than 1 per cent. iron, 0·5 per cent. manganese, and 0·15 per cent. carbon. Cobalt may replace nickel up to 1 part in 5. Examples claimed are (*a*) nickel 75·2, aluminium 8·4, molybdenum 15·8, iron 0·4, silicon 0·24, carbon 0·03, per cent., (*b*) nickel 66·5, aluminium 7·0, molybdenum 25·5, iron 0·8, silicon 0·16, carbon 0·03, per cent. Results of tests at 815°C. are given. The alloys are suitable for gas-turbine blades.

H. V. KINSEY, assignor to HIS MAJESTY THE KING in the right of Canada, as represented by the Ministry of Mines and Technical Surveys.
U.S. Pat. 2,542,962.

Treatment of Creep-Resisting Precipitation-Hardenable Alloys

Treatment of precipitation-hardenable austenitic alloys of chromium, nickel and iron and/or cobalt base comprises (1) rapid refinement of the grain by a series of controlled working and reheating cycles at temperatures of 2050° - 2300°F. (1120° - 1260°C.), (2) working to a semi-finished state, (3) working at a temperature as high as possible without producing recrystallization (1550°-2000°F.: 842°-1093°C.), (4) solution treatment at 1700° - 2300°F. (925° - 1260°C.), to recrystallize the alloy completely to the desired grain size, and (5) ageing at 1350°-1700°F. (735°-925°C.), to produce maximum hardness and stability.

H. SCOTT, R. B. GORDON and F. C. HULL, assignors to WESTINGHOUSE ELECTRIC CORPN. *U.S. Pat.* 2,545,862.

Production of Chromium-Oxide Coatings on Heat-Resisting Alloys

Oxide coatings are produced on composites consisting of a core of chromium-iron, nickel-chromium or iron-nickel-chromium and a layer of another metal, by heating in a non-oxidizing atmosphere at 800°-1100°C. Chromium diffuses out of the core and through the metallic surface layer to the outside, and is there converted into chromium oxide.

PHILIPS LAMPS, LTD. *Brit. Pat.* 650,681.

Production of Low-Carbon Stainless Steel

Chromium-nickel steel of carbon content less than 0·03 per cent. is produced by melting, in an electric-arc furnace having carbonaceous electrodes, a charge consisting principally of chrome ore, base-steel scrap and stainless steel scrap, and an oxidizing material consisting of nickel oxide. A chromium-rich and iron-rich bath having a low carbon content is thus formed, with a supernatant slag containing chromium and nickel oxides. A silicon-containing agent of low carbon content is added to the slag, to recover the metallic chromium and nickel from their oxides.

ALLOY RESEARCH CORPN. *Brit. Pat.* 653,382.

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Registered Trade Marks.*

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